Silicon Spintronics: Recent Advances and Challenges

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The extraordinary increase in performance of integrated circuits has been continuously supported by the uninterrupted miniaturization of MOSFETs, electronic components, and interconnects. Among the most crucial technological changes lately adopted by the semiconductor industry is the introduction of a new type of multi-gate three-dimensional (3D) transistors [1]. With forseeable saturation of scaling CMOS devices the electron spin attracts much attention as a complement or even a replacement of the electron charge in digital information processing. The key advantages of all spin-based computing as compared to a CMOS processor with equivalent functions are zero stand-by power, smaller device count, and lower supply voltage and thus dynamic power [2].Silicon predominantly consists of non-magnetic ^{28}Si nuclei and is characterized by a weak spin-orbit interaction. Because of these properties the electron spin lifetime in silicon is long, which makes silicon perfectly suited for spin-driven applications. However, even a demonstration of basic elements necessary for spin-related applications, such as spin injection, detection, and propagation was missing until recently.The nature of the higher-than expected magnitude of the spin accumulation signal within the three-terminal method is under intense discussion [3], [4], [5], [6] and more research is needed to resolve the controversies.

The excess spin is not a conserved quantity:While diffusing, it gradually relaxes to its equilibrium value which is zero in a non-magnetic semiconductor.The electron spin lifetime is determined by the intervalleyspin-flip processes.Uniaxial stress along [110] direction lifts the degeneracy between the valleys completely in (001) silicon films [7]. This results in a giant spin lifetime enhancement [8]. Strain techniques are now routinely used to boost the electron mobility. It is straightforward to apply the same techniques to obtain a spin lifetime above 1ns making silicon films and fins perfect spin interconnects.

Although significant progress in understanding spin injection, transport, and detection in silicon has been achieved, more research is urgently needed to increase the spin injection efficiency at room temperature and to resolve the issue of spin manipulation by pure electrical means. The most viable option for practical spin-driven applications in the near future is to use magnetic tunnel junctions (MTJs). MTJ-based spin transfer torque MRAM is CMOS compatible, non-volatile, and scalable. It is fast and, in addition, characterized by an infinite endurance and high density. 64Mb MRAM arrays are already in production. A combination of anMTJ with a MOSFETopensa new opportunity to builtinnovative non-volatile logic-in-memory systems [9].

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